PERFORMANCE REPORT

A Cockroach-Like Hexapod Robot for Natural Terrain Locomotion

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Research Progress

Testing determined that the center of pressure (COP) was not being placed as desired by Robot III's posture controller because of friction in the mechanics and unknowns in the control hardware. This caused the robot to stumble when legs entered the swing phase. Cockroaches have a complex system of load sensors on each of their legs that can be used as feedback in posture control. The posture controller was modified to use strain gauges on its tibias for load feedback. The leg loads are used to measure the actual COP and a proportional controller drives the actual COP toward the desired COP. The algorithm works, but more load sensors must be added to the robot's legs. A single semi-conductor strain gage had been mounted at the proximal end of each tibia on Robot III. This configuration is satisfactory for foot-ground contact sensing to determine when the foot should transition from swing to stance. However, it is not sufficient to determine loads in all three directions. Semi-conductor strain gages also tend to drift with even small temperature changes. Four foil gages are now being mounted to each tibia to accurately measure load on each leg. One of the rear legs has been modified for this purpose, four gages have been attached to it, the resulting load cell has been calibrated. Amplification and filtering circuits are now being designed for its operation.

The leg movements and muscle activity associated with cockroach climbing movements are being analyzed and compared to the basic data set on horizontal walking in anticipation of submitting a publication on climbing strategies early next year. The animal appears to go through a hierarchy of strategies to handle ever more difficult barriers. The lowest barriers are traversed with a tripod gate that is very similar if not identical to leg movements associated with normal walking. Barriers that are 25% of the animals body length require a change in strategy including a rotation of the middle leg so that extension pitches the animal upward. Extension of the hind legs then pushes the animal up and over the barrier. At even higher barriers both legs move simultaneously to generate greater pitch and stronger climbs. In addition, intracellular studies of individually identified motor neurons and local interneurons taken during tethered walking and searching are beginning to reveal the underlying electrical activity that controls important motor activity during those behaviors.

Our analyses of one of the three major interleg influence mechanisms in the stick-insect leg coordination model has been extended to a second mechanism. Once again, we have mathematically analyzed the asymptotic relative phase of two oscillators coupled by this mechanism and how this relative phase varies with changes in parameters. This second mechanism exhibits qualitatively new dynamical behavior as compared to the first one we analyzed. In addition, we have also derived analytical phase density plots for both mechanisms and compared these results to simulation (previously, we had only derived expressions for the phase density boundaries). We have also now analytically characterized the layout of the

asymptotic return maps for both mechanisms in parameter space (previously, we had only characterized the parametric layout of the first return maps). Work has just begun on the third interleg influence mechanism, which once again introduces qualitatively new dynamical features.

We have made further progress towards understanding the neural control of muscular hydrostatic structures. Using genetic algorithms, we have successfully "evolved" five networks for a model tongue whose performance is over 99% of the best performance possible, based on an analysis of the physical properties of the tongue model. The actual movements of the tongue that are induced by these controllers overlap almost completely with the best trajectories predicted by the physical analysis, but show more variation in the regions in which the actual length of the tongue is not critical for performance. Furthermore, the ratio of the activations of the two muscles in the model tongue shows significant overlap in the best evolved controllers. These studies provide a benchmark for analysis of other neural network controllers for control of the model tongue. These studies are likely to have implications for the neural control of biological tongues, as well as for the design of controllers for hydrostatic robots.

Publications

Bachmann, R. J., Nelson, G. M., Flannigan, W. C., Quinn, W. C., Watson, J. T., Tryba, A. K., Ritzmann, R. E. (1998). A robot based upon cockroach biomechanics. IASTED International Conference, Robotics and Manufacturing (RM'98), Banff, CA, July 26-29, 1998.

Beer, R.D., Chiel, H.J., Quinn, R.D. and Ritzmann, R.E. (1998). Biorobotic approaches to the study of motor systems. *Current Opinion in Neurobiology* **8**:777-782.

Beer, R.D., Chiel, H.J. and Gallagher, J.C. (in press). General principles and individual variability in evolved model CPGs for walking: Neural and biomechanical constraints. To appear in *J. Computational Neurosci.*

Chen, C. T., Quinn, R. D., and Ritzmann, R. E. (in press). The cockroach escape response circuit provides an excellent basis for a crash avoidance system. To appear in K. Hirota and T. Fukuda (Eds.), *Soft Computing in Robotics*, Springer.

Chiel, H.J., Beer, R.D. and Gallagher, J.C. (in press). Dynamical modules in an evolved model CPG for walking. To appear in *J. Computational Neurosci.*

Kolacinski, R. M. and Quinn, R. D. (1998). A novel biomimetic actuator system. *Robotics and Autonomous Systems* **25**:1-18.

Nelson, G. M. and Quinn, R. D. (in press). Posture control of a cockroach-like robot. To appear in *IEEE Control Systems.*

Quinn, R. D. and Ritzmann, R. E. (in press). A bio-robotics strategy that leads to advances in robotics and biology. To appear in *Connection Sciences.*

Presentations

R. Beer gave an invited lecture at the Neuromorphic Engineering Workshop, Telluride, CO, June 29 – July 19, 1998.

R. Beer gave an invited talk at the Annual Conference of the Biomedical Engineering Society, Cleveland, OH, Oct. 10-13, 1998.

R. Beer gave an invited seminar at the NSF ERC in Neuromorphic Engineering, Caltech, Pasadena, CA, November, 1998.

A. Calvitti gave an invited talk at the Annual Conference of the Biomedical Engineering Society, Cleveland, OH, Oct. 10-13, 1998.

H. Chiel gave an invited talk in the Modeling Neural Systems Symposium at the Fifth International Congress of Neuroethology, San Diego, CA, August 23-28, 1998.

R. Quinn gave an invited talk in the Locomotion and Robotics Symposium at the Fifth International Congress of Neuroethology, San Diego, CA, August 23-28, 1998.

R. Quinn gave a talk at AIRTC'98, Grand Canyon, AZ, October 5-8, 1998 (Received Best Paper Award).

R. Quinn gave an invited talk at the Biology and Robotics Symposium of the AAAI Fall Symposium Series, Orlando, FL, October 22-25, 1998.

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